ACCOMPLISHMENT REPORT

PROPULSION DIRECTORATE
August 2000

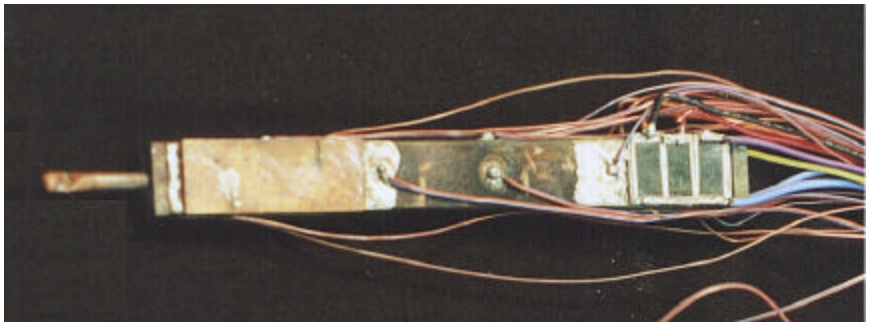
TEAM INCLUDING PR SCIENTIST WINS R&D 100 AWARD: Among the winners of the 2000 R&D 100 Awards is the team of Dr. Shawn Phillips of the Propulsion Directorate, Drs. Joe Lichtenhan and Joe Schwab of Hybrid Plastics, and Prof. Frank Feher of the University of California, Irvine. Since 1963, *R&D Magazine* has honored inventors by identifying the 100 most technologically significant products and advancements for each year and recognizing the winners with the R&D 100 Award. The Chicago Tribune has called these awards "The Oscars of Invention," and others have referred to them as the "Nobel Prizes of Applied Research." Past winners include such breakthrough products as Polacolor film, the flashcube, the digital wristwatch, antilock brakes, the automated teller machine, the liquid crystal display, the halogen lamp, and the fax machine. The team was recognized for the development and commercialization of new Nanostructured Chemical Feedstocks for polymers referred to as Polyhedral Oligomeric Silsesquioxanes (POSS). In particular, the award acknowledges the development of nanostructured chemicals that reinforce plastics while providing optical transparency. (S. Phillips, AFRL/PRSM, (661) 275-6270)

R&D100 Award winners

[For more information on the R&D 100 Awards, see R&D Magazine's website at http://www.rdmag.com/scripts/100award.asp]

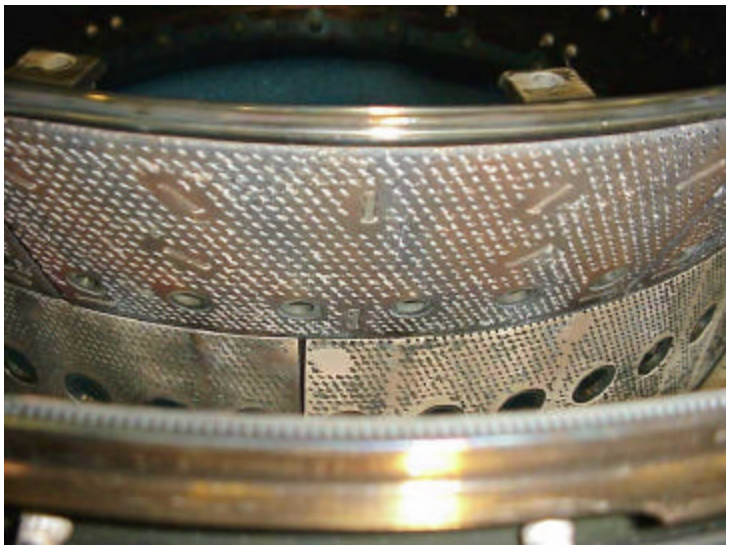
FLAT MINIATURE HEAT PIPE FOR LASER DIODE COOLING: Performance tests on a set of eight new flat miniature heat pipes (FMHPs) have been successfully completed at the Propulsion Directorate's Thermal Laboratory (AFRL/PRPG). The FMHP holds great promise for isothermalization and cooling of electronics, including laser diodes. The University of Connecticut (UConn), under a PRPG-managed program sponsored by the Ballistic Missile Defense Organization, had earlier demonstrated copper-water axial groove wick FMHPs at heat fluxes in excess of 100 W/cm^2. Although these devices had remarkable performance, they were very difficult and costly to manufacture. Under an in-house program, PRPG researchers conceived, designed, and fabricated a novel copper-water heat pipe. Eight experimental heat pipes with folded-screen folded-sheet fin wick designs were fabricated and tested. New manufacturing processes for fin-forming, brazing, and filling have worked extremely well in preliminary heat pipe fabrication attempts. The in-house effort has demonstrated that the expensive and difficult process of conventional fine-groove machining could be easily replaced with these simple, much more affordable wick designs. Experimental results of the new FMHPs also show superior performance when compared with the available performance data of UConn's FMHPs. The

new design ideas and the fabrication techniques for FMHPs will make these important devices far more suitable to large-scale production. (R. Ponnappan and J. Leland, AFRL/PRPG, (937) 255-2922)



Instrumented copper-water flat miniature heat pipe

IHPTET COMBUSTOR TESTING COMPLETE: Pratt & Whitney recently completed rig testing of an Impingement Film Floatwall (IFF) Combustor for the Integrated High Performance Turbine Engine Technology (IHPTET) Phase III Advanced Turbine Engine Gas Generator (ATEGG). The combustor technology demonstrated in this rig test provides critical design characteristics to support Joint Strike Fighter (JSF) engine development. The IFF combustor rig completed over 16 hours of hot time via two builds. The rig demonstrated extremely high fuel/air ratios with a very low pattern factor and temperature profile. High fuel/air ratios are needed to reach IHPTET turbine inlet temperature goals, and low pattern factor and temperature profile are needed to maintain turbine blade life. Ceramic Matrix Composite (CMC) combustor panels showed evidence of distress, and they will be replaced by metallic liners for the ATEGG core test. CMC panels are needed to achieve the IHPTET Phase III temperature and cooling effectiveness goals which will be demonstrated in the second build of the ATEGG core. The first build of the ATEGG core is scheduled to begin testing in November 2000 at Arnold Engineering Development Center. (D. Jay, AFRL/PRTP, (937) 255-2278)

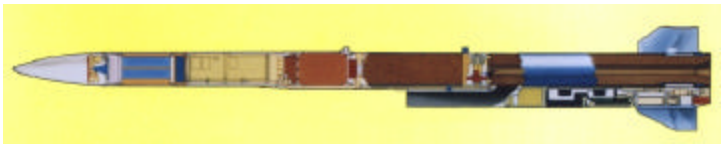


IFF combustor panel

VFDR TECHNOLOGIES IMPACTING CRITICAL NAVY PROGRAM: The Variable Flow Ducted Rocket (VFDR), a now complete Propulsion Directorate program, is making significant contributions to the Navy's new Supersonic Sea Skimming Target (SSST) Program. The VFDR is an airbreathing propulsion system enhancement originally targeted for AMRAAM and HARM missiles. Though this propulsion system was never fielded, a number of technologies were successfully developed

under VFDR that are now impacting development of the SSST. Among these technologies are a reduced smoke booster, an advanced flow control valve to throttle the ducted rocket, DC-93-104 insulation, and an end-burning solid hydrocarbon fuel grain for ducted rocket operation. The adoption of these VFDR technologies will aid in successful development of the SSST. The SSST missiles are targets designed to provide a realistic simulation of supersonic anti-ship cruise missile threats for test and evaluation of ship self-defense systems. Success in this program is of critical importance, because the Navy views anti-ship supersonic cruise missiles as their number one threat. (B. Mercier, AFRL/PRSC, (937) 255-6814)

SSST



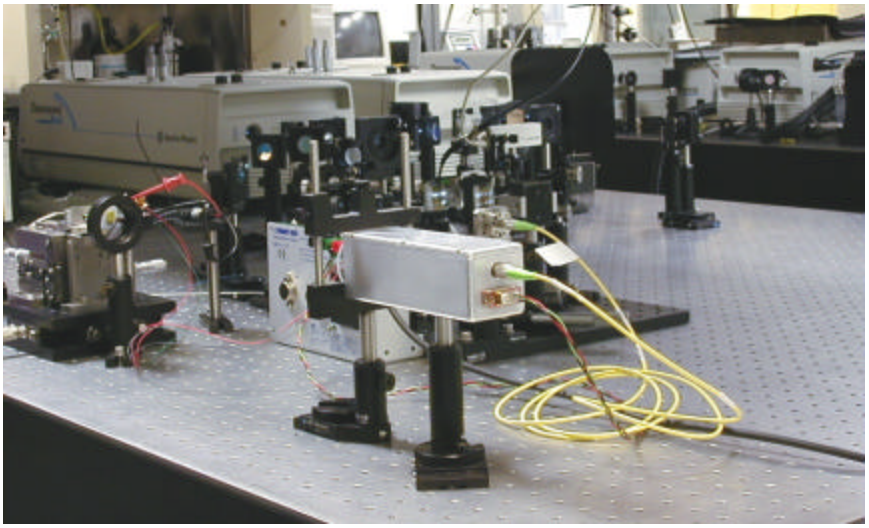
VFDR

SOLID BOOST DEMO TEST APPROACHING: The Integrated High Payoff Rocket Propulsion Technology (IHPRPT) Phase I Solid Boost Demonstration Program is making progress toward a November 2000 test date. During July of this year, 108,000 pounds of propellant were successfully cast in a full-scale Castor 120® rocket motor case. The case was prepared and lined during the first three weeks of July, and the propellant was cast during the final week. Nineteen 600-gallon loads of propellant were used. In August, the core will be removed and the propellant machined. In addition, the final nozzle sub-component, the exit cone, was assembled and the electromechanical thrust vectoring assembly (EM TVA) underwent final checkout. Final assembly will commence in September 2000, and the static test firing of the demonstrator is scheduled for 16 November 2000. The goal of this program is to demonstrate new and improved materials in the case, propellant, nozzle, and thrust vector control in a Castor 120® size motor. These improvements will yield 23 percent more payload at a 32 percent lower cost for medium space lift applications. (L. Quinn, AFRL/PRR, (661) 275-5630)

HIGH CYCLE FATIGUE ASSESSMENT COMPLETED: Hood Technology Corp recently completed spin pit demonstration of their eddy current excitation system (ECES) on an 11-inch titanium rotor. This work is being performed under a Propulsion Directorate Phase II SBIR contract with additional support from the Naval Air Warfare Center. The goal of this effort is to develop an ECES for use in experimental spin pits that induces rotor blade vibrations to evaluate high cycle fatigue (HCF) properties/life of a rotor. This test was completed at the Naval Postgraduate School's 60-inch spin pit facility on a small-scale rotor as a precursor to a full-scale demonstration on a Joint Strike Fighter fan rotor later this year. The test was performed at speeds up to 25,000 rpm with vibratory stresses induced in the blades to levels sufficient to incur HCF damage in the blades. The full-scale system will be constructed in conjunction with a blade-tip time of arrival measurement system to finalize the completely non-intrusive HCF testing capability. This technology will provide engine developers with a

testing technique to evaluate a rotor for HCF life during the development phase at approximately 10 percent of the cost of current engine or rig testing methods. Affordable HCF testing during engine development will eliminate many HCF problems before the engines are fielded, resulting in significantly reduced engine maintenance costs and potential aircraft losses. (F. Lieghley Jr., AFRL/PRTC, (937) 255-1867)

NEW OPTICAL DIAGNOSTIC TOOL DEMONSTRATED: Researchers in the Propulsion Directorate's Combustion and High Speed Systems Branch (AFRL/PRSC) recently constructed and demonstrated the world's first terahertz asynchronous optical sampler (THz-ASOPS). This work was performed collaboratively with scientists and engineers from Picometrix, Inc, of Ann Arbor, MI and Innovative Scientific Solutions, Inc, of Beavercreek, OH. THz-ASOPS is a new laser-based tool that exploits the unique spectral characteristics of terahertz radiation and the rapid temporal scanning achievable with asynchronous optical sampling to provide high-bandwidth data-acquisition capability for diagnostic studies of combustion and aviation fuel. The THz-ASOPS hardware will also be beneficial to many other applications of terahertz radiation or "T-rays." Some of these applications include imaging traces in semiconductor chips, inspecting packages and luggage, counting raisins in cereal boxes, and even measuring moisture content in Twinkies®. (J. Gord, AFRL/PRSC, (937) 255-7431)



THz-ASOPS System

AIR FORCE/DoE LABS COLLABORATE ON SUPERCONDUCTIVITY RESEARCH: A joint research effort between the Argonne National Laboratory (ANL) and the Propulsion Directorate's Superconductivity Group (AFRL/PRPS) was recently initiated. The purpose of this collaboration is to study the effects of substrate surface roughness on the ion beam assisted deposition (IBAD) process for YBCO (yttrium barium copper oxide) coated conductors. Surface roughness is accepted in the coated conductor community as being important, but it is acknowledged that a systematic study of its effect has yet to be performed. These studies will be tied to investigations performed by the AFRL Superconductivity Group (PRPS & MLPO) which involve substrate surface roughness effects on the textured substrate approach known as the deformation texture (DeTex) or rolling assisted biaxially

textured substrate (RABiTS) approach. Using the IBAD method, ANL has deposited on substrates prepared at Wright-Patterson AFB, Ohio. These samples are currently being evaluated by AFRL. The YBCO coated conductor is used in coil windings for cryogenic power generators required for future airborne directed energy applications. (P. Barnes, AFRL/PRPS, (937) 255-2923)

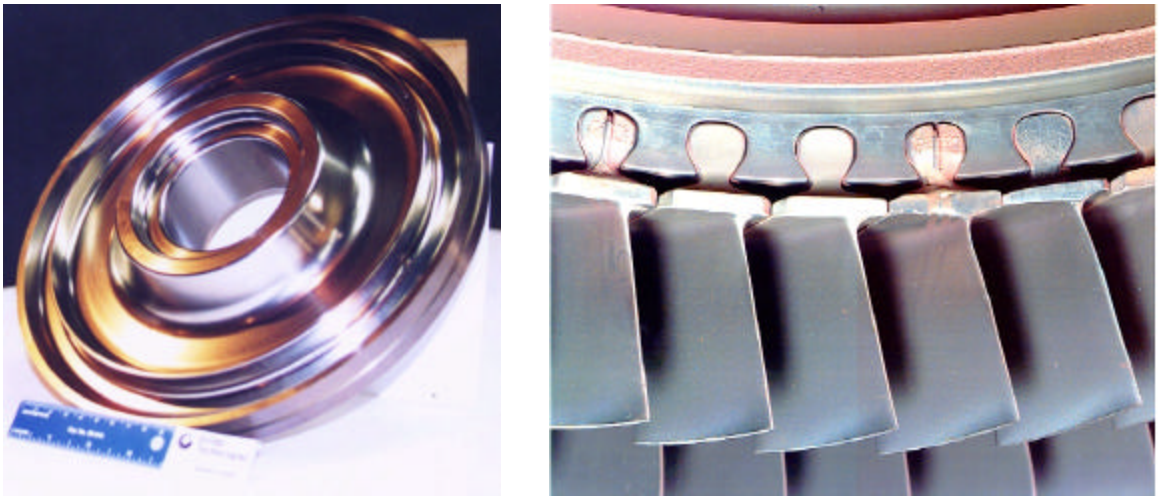
ADVANCED ROCKET COMBUSTION CHAMBER CLOSER TO TEST: Progress is being made towards testing the Advanced Expander Cycle (AEC) Combustion Chamber for the Upper Stage Demonstrator (USD) Program. The USD Program contributes to Integrated High Payoff Rocket Propulsion Technology (IHPRPT) Phase III orbit transfer goals by doubling the thrust of the RL-10 engines used for the Centaur upper stage of Atlas launch vehicles. Stage costs can be reduced by 50 percent and payload increased by 22 percent by replacing the Centaur's two RL-10 engines with a single engine. In recent AEC testing, the ignition system successfully fired and demonstrated the torch ignition method. Also, a successful phenolic chamber test was conducted that verified injector capability, igniter functionality, facility valve timing and control, and proper oxidizer/fuel control. Nickel plating of the AEC combustion chamber is now complete, and it has been shipped to Pratt & Whitney for final preparations for tests to be conducted later this year. (L. Quinn, AFRL/PRR, (661) 275-5630)

Various microtubes shown relative to the size of a human hair

TECHNOLOGY HORIZONS ARTICLE SPURS INTEREST IN MICROTUBES: An article published in the June 2000 issue of *AFRL Technology Horizons* has spurred commercial interest in microtubes. The article, titled "Microtube Technology Has Diverse Applications," briefly describes potential applications for microtubes. Researchers in the Propulsion Directorate's Propulsion Materials Applications Branch (AFRL/PRSM) have pioneered work in microtubes, and have earned five patents for their efforts. These microtubes, which are so small that dozens can fit in the diameter of a human hair, yield wide-ranging applications. The article cites specific automotive and medical applications for microtubes, and myriad other uses are envisioned. As a result of the microtube article, ITT Night Vision in Roanoke, VA inquired about using microtube technology to make microchannel plate structures for night vision. In addition, a representative of MicroCoating Technologies, Inc inquired about working with PRSM on this technology. Efforts are under way to develop relationships with these companies. (W. Hoffman, AFRL/PRSM, (661) 275-5768)

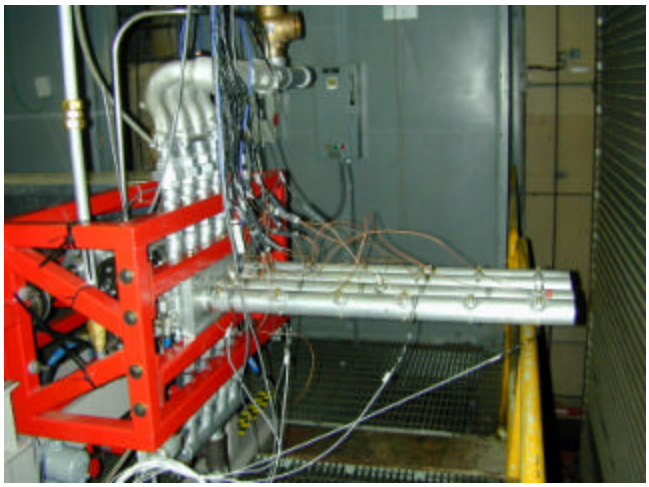
ANALYSIS KEEPS γ-TiAl IN IHPTET PHASE III PLAN: As a result of a foreign object damage (FOD) event that occurred during the CAESAR engine (XTE-66/SE) test, three 9th stage gamma titanium aluminide (γ-TiAl) blades were liberated. Following that FOD event, Pratt & Whitney (P&W)

performed an analytical simulation to determine if a blade loss in an all γ-TiAl rotor would decob the rotor. Results from that simulation indicated that the loss of a single γ-TiAl airfoil would result in the loss of several of the following airfoils and potentially the entire rotor. This result put the use of γ-TiAl, which is currently in the Integrated High Performance Turbine Engine Technology (IHPTET) Phase III plan, in question. AFRL, with the assistance of the University of Dayton Research Institute, developed a two-phase approach to conduct an independent evaluation of the blade-out analysis performed by P&W with the purpose of determining if a realistic FOD event would cause blade loss in an all γ-TiAl rotor. The two phases consist of (1) performing an independent analytical prediction of the γ-TiAl failure, and (2) FODing a set of γ-TiAl and nickel compressor blades and performing high cycle fatigue (HCF) tests on them. The first phase of this evaluation has been completed. It was determined that some conditions imposed in the original analysis were exceedingly severe and some parameters used were incorrect; consequently, the analysis indicated unrealistically poor performance. In view of these findings, P&W made the decision to maintain the current Phase III plan, which still includes γ-TiAl. The experimental work in the second phase of the plan will be completed in the late fall of 2000. At that time, questions about the viability of an all γ-TiAl rotor can be addressed with a higher degree of confidence. (K. Sargent, AFRL/PRTC, (937) 255-2081)



γ-TiAl subscale rotor (left) and compressor blades (right)

STUDIES OF PULSED DETONATION ENGINES PROGRESSING: Researchers in the Propulsion Directorate's Combustion and High Speed Systems Branch (AFRL/PRSC) continue to make progress in the study of Pulsed Detonation Engines (PDEs). The PDE is an advanced engine concept that holds the promise of outstanding propulsion performance from an engine that is relatively simple and cheap to manufacture. PRSC developed an in-house test facility at Wright-Patterson AFB, Ohio, to study PDEs, and testing in this facility has set benchmarks for low cost, extreme durability (by two orders of magnitude), extended run times, number of detonation tubes, and frequency range. The engine has also demonstrated the feasibility and advantages of running PDEs premixed. Furthermore, the in-house PDE was recently modified with liquid cooling systems and an expanded fuel system to permit continuous runs of hours in duration. It is estimated that approximately 12 million detonation cycles have been accomplished with this first generation hardware. Several researchers have used PRSC PDE data to



The in-house pulsed detonation engine

benchmark their work and others have approached PRSC about future collaborative work using PRSC's unique PDE research capabilities. Recently, PRSC's Quad-4 cylinder head based PDE was destroyed when several washers securing detonator tubes to the 16-valve head catastrophically failed. Fortunately, replacement cylinder heads, at a cost of only $300, were already undergoing buildup. The new heads will replace the first generation PDE and incorporate numerous design improvements. (J. Stutrud and F. Schauer, AFRL/PRSC, (937) 255-6462)

SUPERCONDUCTIVITY GROUP HONORED BY CORPORATE PARTNER: Intermagnetics General Corp (IGC) presented a plaque to the AFRL Superconductivity Group, which includes researchers in both the Propulsion and Materials Directorates. The plaque expresses IGC's appreciation for the support of AFRL in the collaborative effort to develop second-generation high temperature superconducting (HTS) conductors. The new IGC SuperPower facility was formally dedicated in Schenectady, NY on 8 June 2000. This facility will be used to establish a manufacturing technology for HTS coated conductors within three years. The YBCO (yttrium barium copper oxide) coated conductor will be deposited on a textured buffered substrate using the ion beam assisted deposition (IBAD) technology. In a letter to the AFRL Superconductivity Group, IGC stated that they are looking ". . . forward to a continuing and growing partnership with the AFRL, which we hope will result in many new technological breakthroughs." (P. Barnes, AFRL/PRPS, (937) 255-2923)

NATO ACCEPTS AFRL'S FUEL THERMAL STABILITY ADDITIVE: During the recent NATO Aviation Fuels and Lubricants Working Party meeting in Brussels, Belgium, the +100 fuel additive developed by the Propulsion Directorate's Fuels Branch (AFRL/PRSF) was a topic of discussion. Both the US and Danish delegates reported on their successful use of the +100 thermal stability additive in military aircraft, and the Canadian delegate reported on Canada's plan to convert their military aircraft to F-34+100 (JP-8+100) by December 2002. As a result of the increasing use of the additive by NATO countries, the French delegate proposed that the +100 thermal stability additive be given a NATO designation code. A NATO code is an identifying letter and number allocated to a product

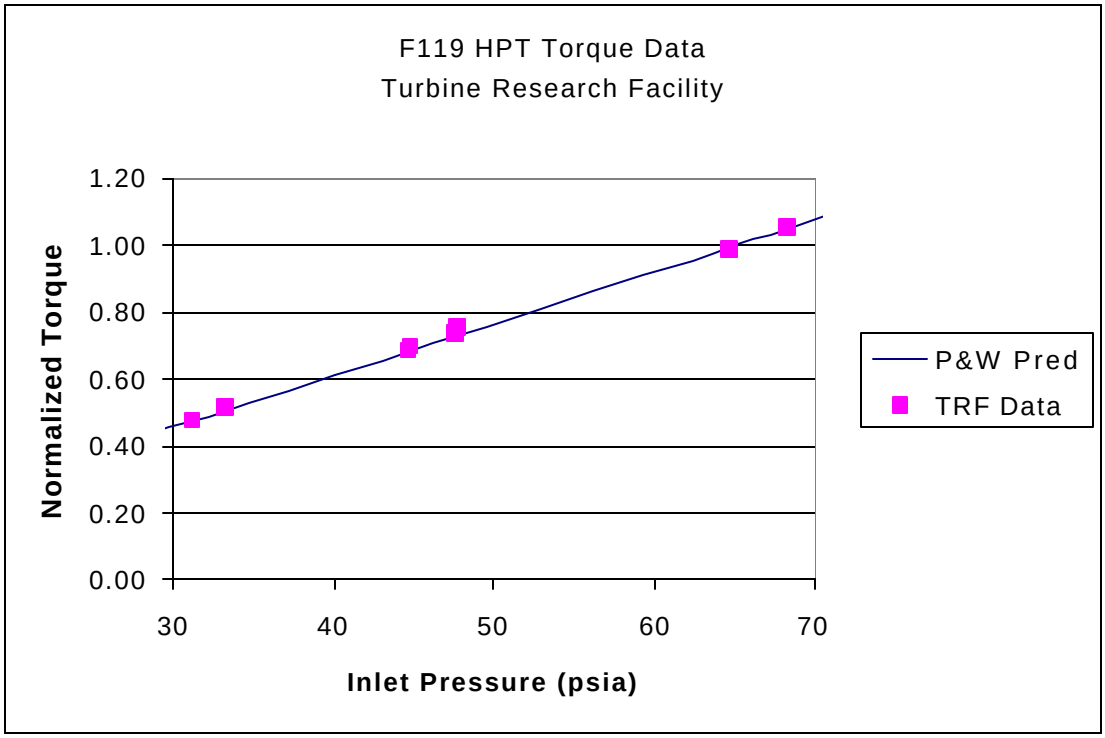
meeting a specification that has been accepted by all NATO countries under a NATO Standardization Agreement. All of the NATO delegates agreed to the French proposal, and by the end of this year, the +100 thermal stability additive and F-34 with the +100 additive will have NATO code designations. This will facilitate the use of the additive by any NATO country in the future, and it marks an important step in the proliferation of the +100 additive to the world aviation community. (P. Liberio, AFRL/PRSF, (937) 255-6918)

A Danish refueller transporting F-34+100 (JP-8+100)

NEW PROGRAM TO DEVELOP ROCKET ENGINE DUCTING: The Propulsion Directorate's Propulsion Materials Applications Branch (AFRL/PRSM) recently initiated a Phase II SBIR with Maxdem, Inc. In a successful Phase I program, Maxdem was tasked with developing polymeric ducting for use in liquid rocket engines with an emphasis on replacing heavy metallic parts (density ~ 10 g/cm^3) with lightweight plastic materials (density ~ 1.4 g/cm^3). To accomplish this goal, Maxdem developed new materials consisting of their trademark polyphenylene polymer called Parmax™ in combination with various quantities of POSS (polyhedral oligomeric silsesquioxanes). POSS additives are known to dramatically upgrade the properties of many plastics, and POSS-Parmax™ polymers demonstrated the increased use temperature needed for high temperature applications. In the Phase II program, the physical and mechanical properties of various POSS-Parmax™ polymers will be investigated further, followed by a later downselect to a single candidate. Scale-up efforts, burst-testing, and extrusion of sub-scale polymer parts will then be conducted. Ultimately, Maxdem will fabricate liquid rocket engine ducting samples and perform full chemical and pressure tests of the parts. (S. Phillips, AFRL/PRSM, (661) 275-5416)

F119 RESEARCH IN TRF SUPPORTS PREDICTION: The Propulsion Directorate's Turbine Research Facility (TRF) is being used to investigate the aerodynamic and heat transfer performance of the F119 high pressure turbine. The first phase of this test validated that the measured mechanical work

of the turbine agrees with predictions. The measurement of the mechanical work was accomplished with a newly installed TRF torque meter. This torque meter also provides an additional means to determine the energy loss due to the overall turbine heat transfer, which must be accounted for in the thermodynamic work calculation. In the testing to follow, the aerodynamic and heat transfer performance will be obtained simultaneously thereby eliminating significant duplication and measurement error associated with variations that occur from multiple tests being performed in different test facilities. This enhanced TRF capability provides a more cost-effective method to perform turbine research and evaluate advanced technologies. (M. Kobelak, AFRL/PRTE, (937) 255-1922)



PRSL DESIGNS NEW CARBON-CARBON CLUTCH BEARING: For the foreseeable future, magnetic bearings will rely on back-up bearings in the event of overload or power out situations. The development of a flight-weight, reliable back-up system has proven to be one of the most challenging aspects of introducing magnetic bearing in the gas turbine arena. There are currently several design concepts being considered for reliable back-up bearings, and one of these designs resulted from a Propulsion Directorate Lubrication Branch (AFRL/PRSL) in-house program. In this design, a carbon-carbon (C-C) clutch is used to intermittently engage the back-up bearing when required. Several advantages of this clutch mechanism include: (1) it closes the available free clearance to avoid unstable shaft modes (e.g., backward whirl), (2) it centers the shaft to minimize rotating unbalance loads, (3) it provides a gradual clamping motion to minimize bearing skidding, and (4) it provides intermittent operation to extend operational life over other concepts such as continuously engaged auxiliary bearings. A further advantage is that the bearing provides much higher load capacity than other intermittent engaging designs that are in the published literature. On 27 June 2000, a patent application was filed by the Air Force covering this design naming PRSL's Garry Givan and Dr. Nelson Forster as the co-

inventors. The hardware design, which is now complete, is for full-scale system hardware compatible with the XTC-77/1 demonstrator engine. Long lead delivery items have been ordered, and the C-C clutch mechanism is scheduled for demonstration in late 2001. (G. Givan, AFRL/PRSL, (937) 255-1286 and N. Forster, AFRL/PRSL, (937) 255-4347)

Patricia Liberio

LIBERIO KEYNOTE SPEAKER FOR UD ENGINEERING BANQUET: Ms. Patricia Liberio of the Propulsion Directorate's Fuels Branch (AFRL/PRSF) was the invited keynote speaker at the University of Dayton's (UD's) "Dinner with an Engineer" held on 12 July 2000. This event was one of the highlights of UD's Women in Engineering Summer Camp 2000. The weeklong program is designed to motivate and assist female students with their careers in engineering. The purpose of the dinner was to give high school girls the opportunity to meet professional women engineers and learn about engineering education and careers. Ms. Liberio spoke to the gathering about her more than 20 years of experience as a government engineer. In addition to the program participants, the audience included women engineers from more than 60 companies. The response to the address was overwhelmingly positive, and the program coordinator called the speech "inspirational." For the past 6 years, Ms. Liberio has been very active in UD's engineering mentoring and career awareness programs. (P. Liberio, AFRL/PRSF, (937) 255-6918)

PRP CONTRACTOR WINS SAE PUBLICATION AWARD: Jim Walton of Mohawk Innovative Technologies, Inc. (MITI) will be honored by the Society of Automotive Engineers (SAE) for submitting one of the best technical publications to the SAE in 1999. The paper (SAE-1999-01-1392), titled "Auxiliary Bearings in Support of Magnetic Bearings for Turbine Engines," describes the efforts to develop an auxiliary bearing for a high-speed turbogenerator. This work was funded through an Air Force Phase II SBIR Program managed by the Propulsion Directorate's Power Division (AFRL/PRP). The goal of this program was to help enable the use of oil-free magnetic bearings as the primary bearing set for the Air Force-funded Integrated Power Unit (IPU) Demonstrator built by Sundstrand Aerospace. MITI's bearing concept, known as the Zero Clearance Auxiliary Bearing or ZCAB, also operates without an oil-feed system to speeds over 60krpm, and is designed to control "backwhirl" and shock loads that are significant risk issues to other auxiliary bearing concepts. The SAE Charles M. Manly Memorial Award to Mr. Walton recognizes his paper as the most outstanding one presented in 1999 relating to theory & practice in the research, design, or construction of aerospace engines and components. (E. Durkin, AFRL/PRPG, (937) 255-6241)